TRIUMF

CANADA'S NATIONAL LABORATORY FOR PARTICLE AND NUCLEAR PHYSICS

Owned and operated as a joint venture by a consortium of Canadian universities via a contribution through the National Research Council Canada

Low Beta North American Activities

R. Laxdal, TRIUMF

TTC Meeting

New Delhi, Oct. 20, 2008

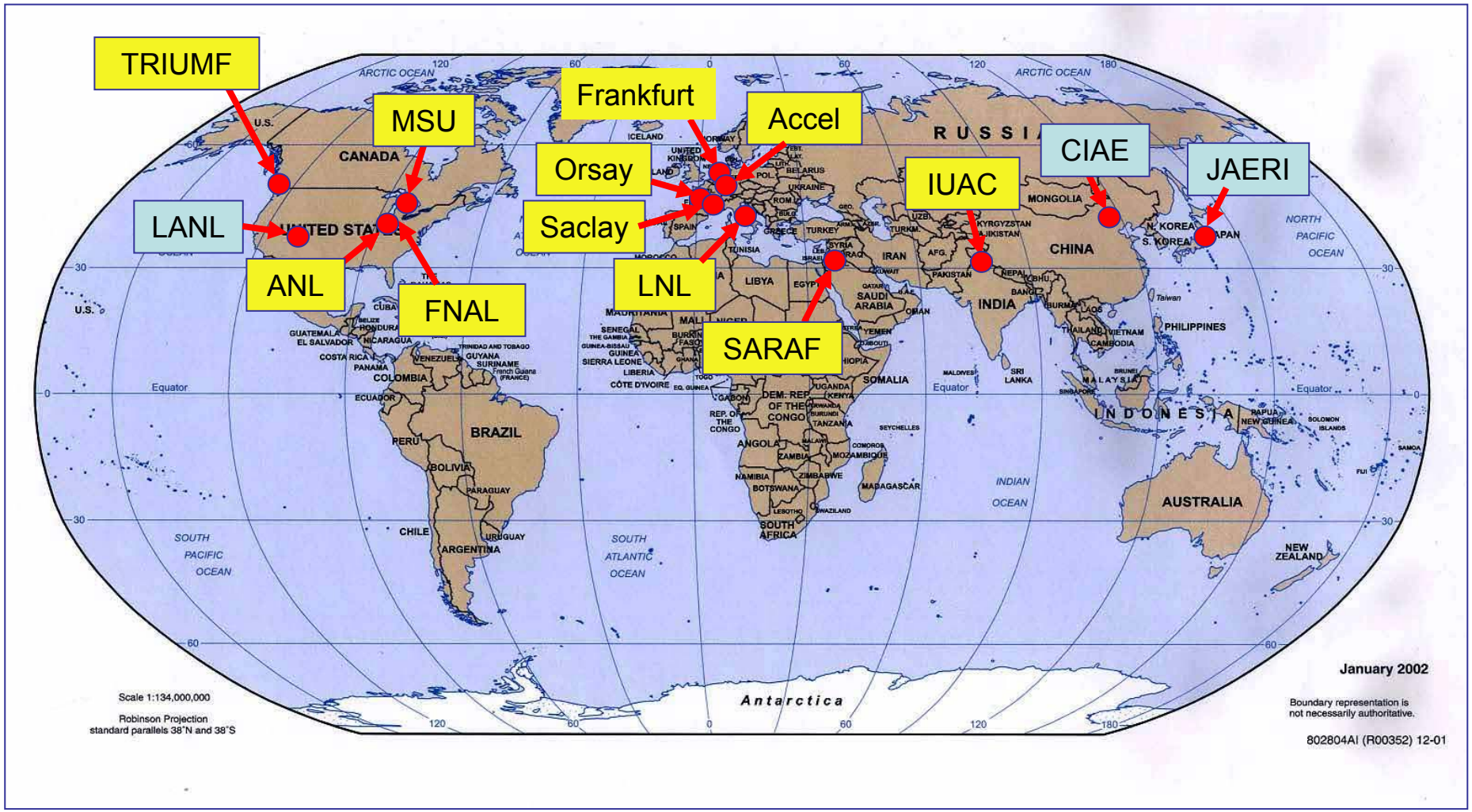
LABORATOIRE NATIONAL CANADIEN POUR LA RECHERCHE EN PHYSIQUE NUCLÉAIRE ET EN PHYSIQUE DES PARTICULES

Propriété d'un consortium d'universités canadiennes, géré en co-entreprise à partir d'une contribution administrée par le Conseil national de recherches Canada

Outline

- Overview of community and goal
  - Existing facilities
    - ANL,ISAC-II
  - MSU-reaccelerator
  - Proposals – in development
    - FRIB, HINS/Project-X, …
- Conclusions

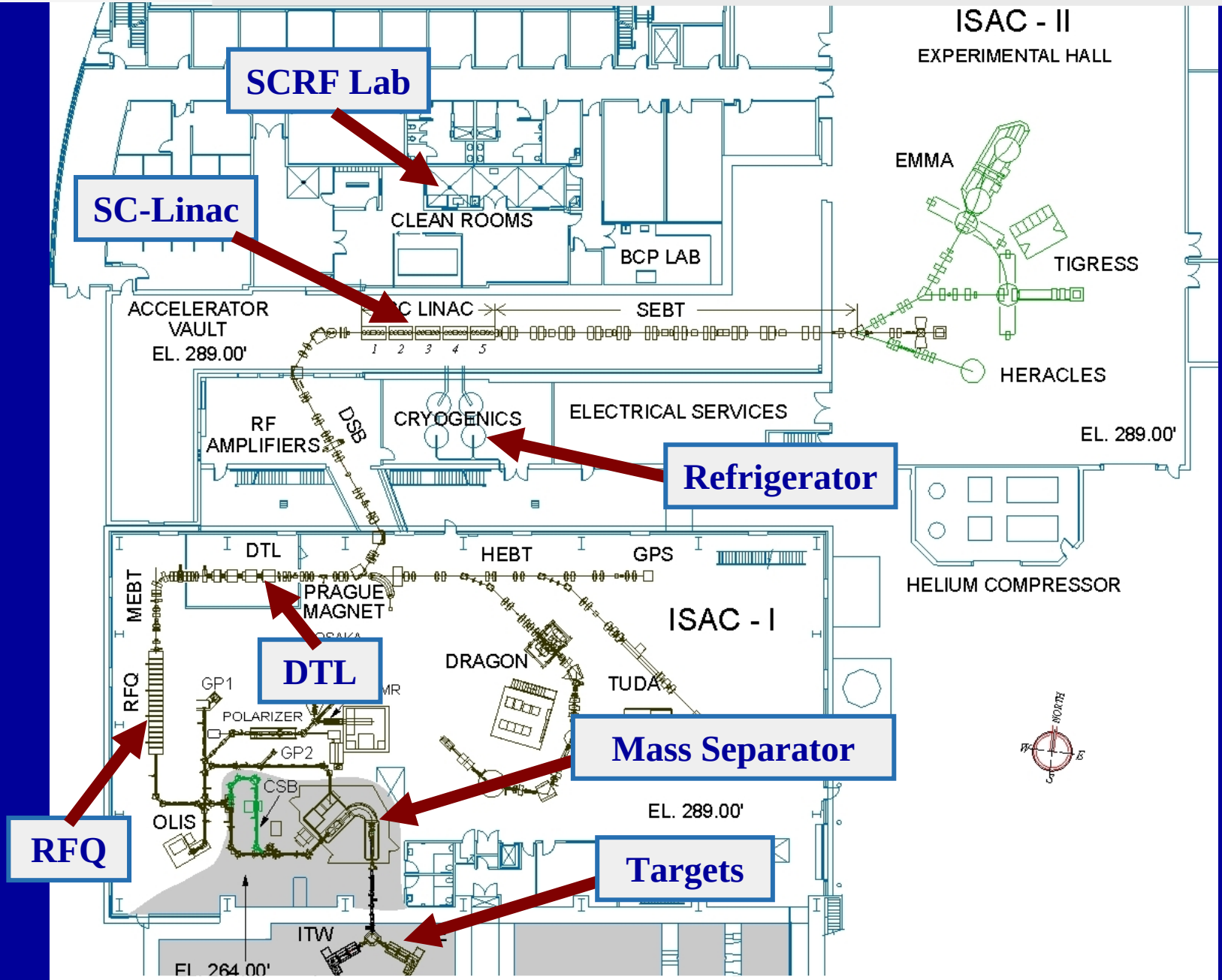
Low-Beta SC (Niobium) Community

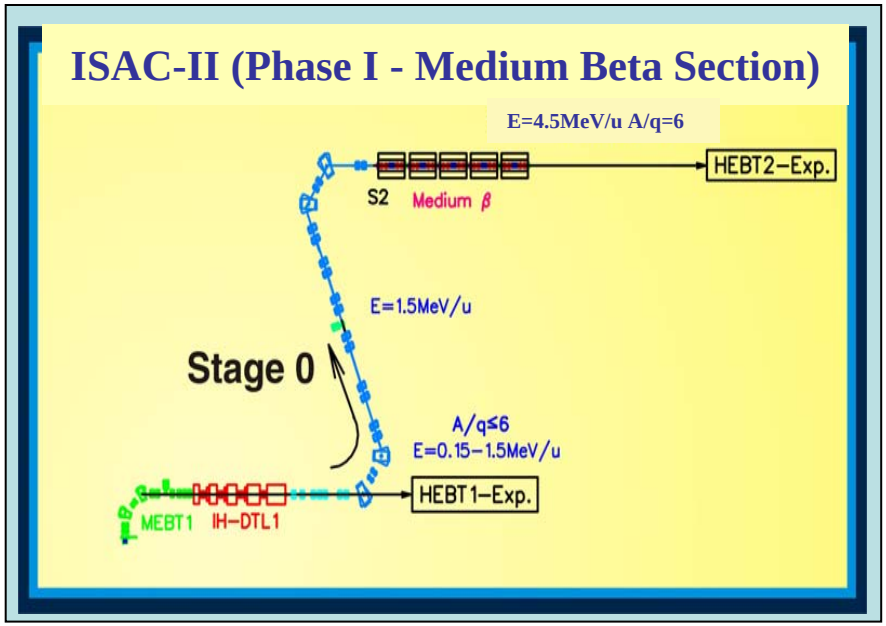


Projects and Proposals at Low Velocity

Project	Lab	Driver	Post-accelerator	Particle	Structure
ISAC-II	TRIUMF		√	HI	QWR
Reaccel	MSU		√	HI	QWR
Upgrade	ANL		√	HI	QWR
FRIB	ANL,MSU	√	√	HI/HI	QWR, HWR, Spoke
HINS/Project x	FNAL	√		P	QWR, HWR, spoke
AAA	LANL	√		P	spoke

TRIUMF


SCRF Lab
SC-Linac
Refrigerator
DTL
Mass Separator
RFQ
Targets
ISAC - II
EXPERIMENTAL HALL
EMMA
TIGRESS
HERACLES
CLEAN ROOMS
BCP LAB
ACCELERATOR VAULT
EL. 289.00'
SC LINAC
SEBT
1 2 3 4 5
RF AMPLIFIERS
DSB
CRYOGENICS
ELECTRICAL SERVICES
EL. 289.00'
HELIUM COMPRESSOR
DTL
HEBT
GPS
MEBT
PRAGUE MAGNET
ISAC - I
DRAGON
TUDA
RFQ
GP1
POLARIZER
GP2
CSB
OLIS
EL. 289.00'
ITW
EL. 264.00'
NORTH



ISAC-II 106MHz Superconducting Linac

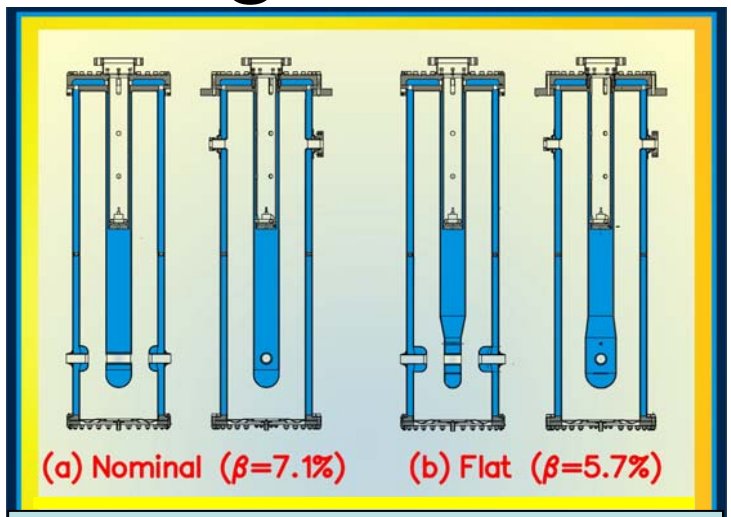
- Twenty bulk niobium quarter wave cavities housed in five cryomodules
- Boosts ion energy by 20MV to provide stable and RIB's above the Coulomb Barrier

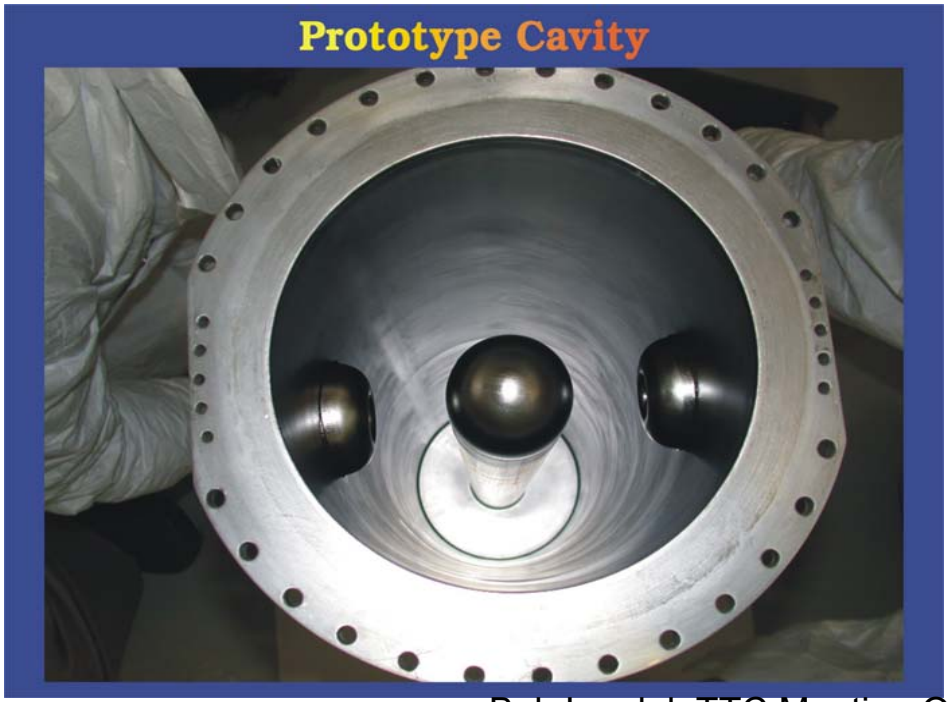
Summary

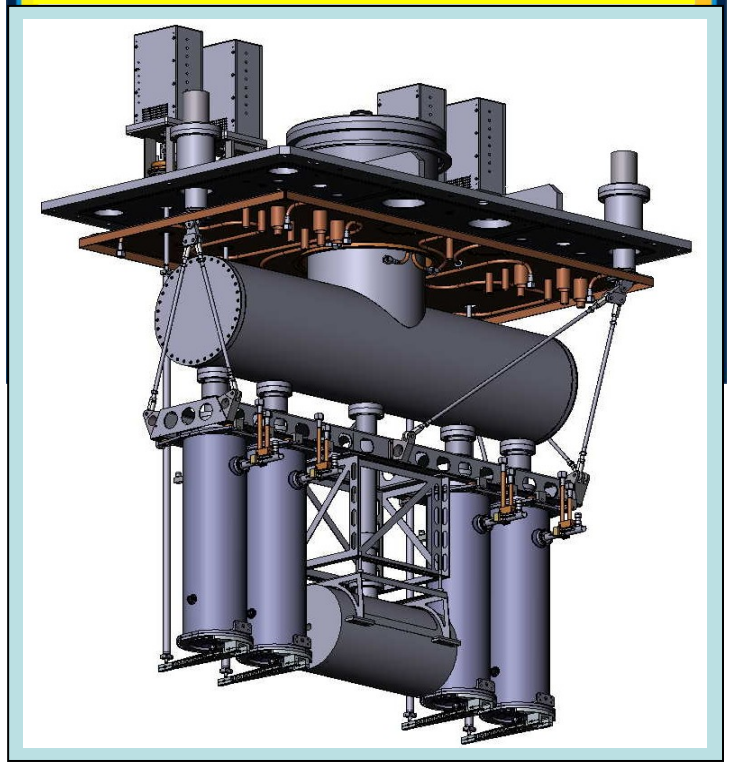
- ISAC-II Accelerator commissioned in Spring 2006 with beam delivery for key experiments in 2007-08

Superconducting Cavities

- Bulk niobium cavities designed in collaboration with INFN-Legnaro
- Fabricated in Italian industry (Zanon) and chemically etched in CERN and J-Lab
- Twenty installed in five cryomodules



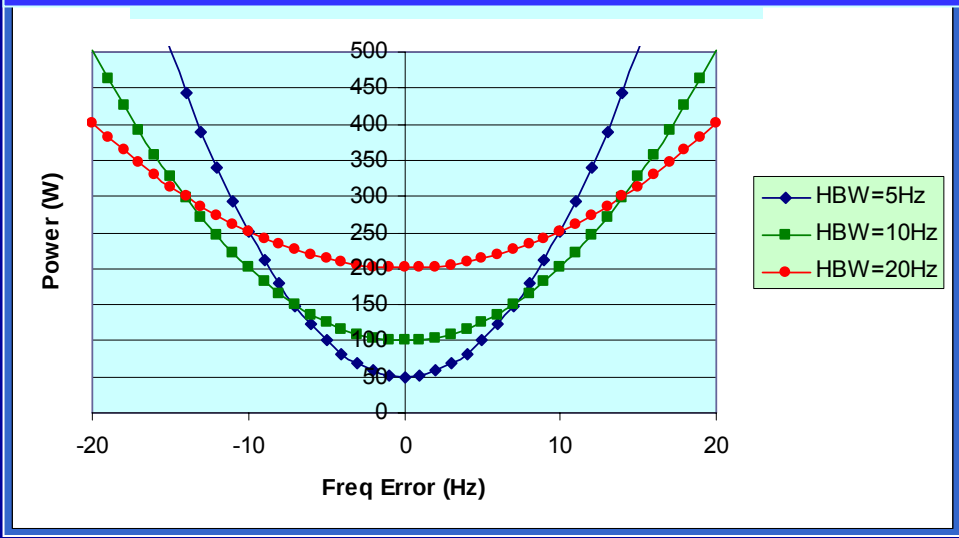




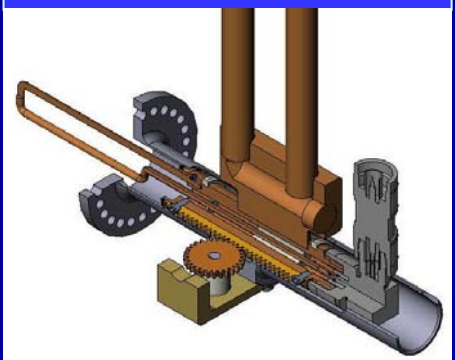
ISAC-II Linac: RF Systems

- RF power
  - Provide useable bandwidth by overcoupling
  - Require P_f=200W at cavity for $f_{1/2}$=20Hz at E_a=6MV/m, β=200
- Coupling loop
  - Developed LN2 cooled loop
  - <0.5W to LHe for P_f=250W
- Mechanical tuner
  - Precise (0.3~Hz), fast (>50Hz/sec) tuner with dynamic range of 8kHz and coarse range of 32kHz
- Tuning plate
  - Spun, slotted, `oil-can' tuning plate to improve tuning range

Forward power required for Ea=6MV/m and given bandwidth

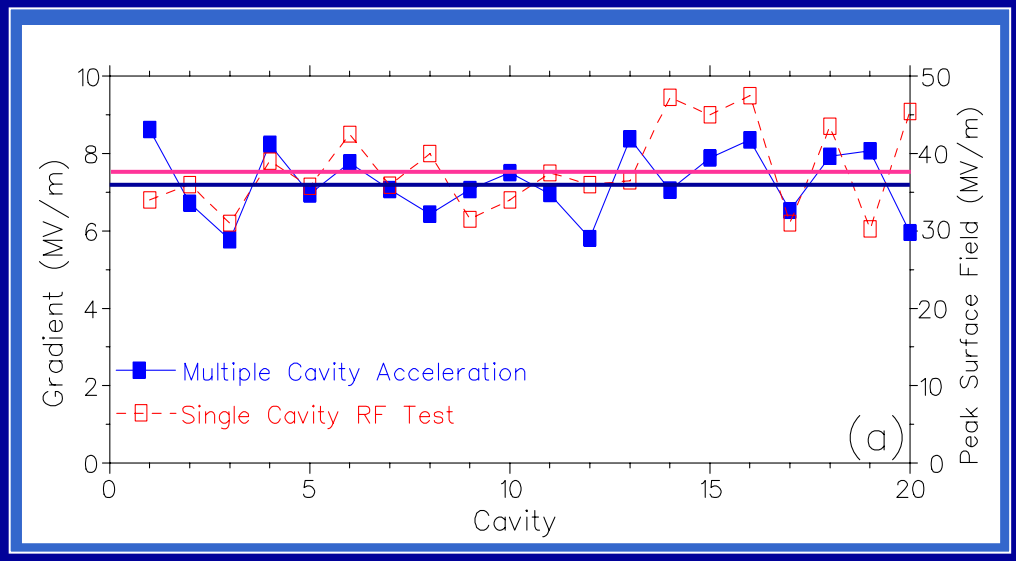


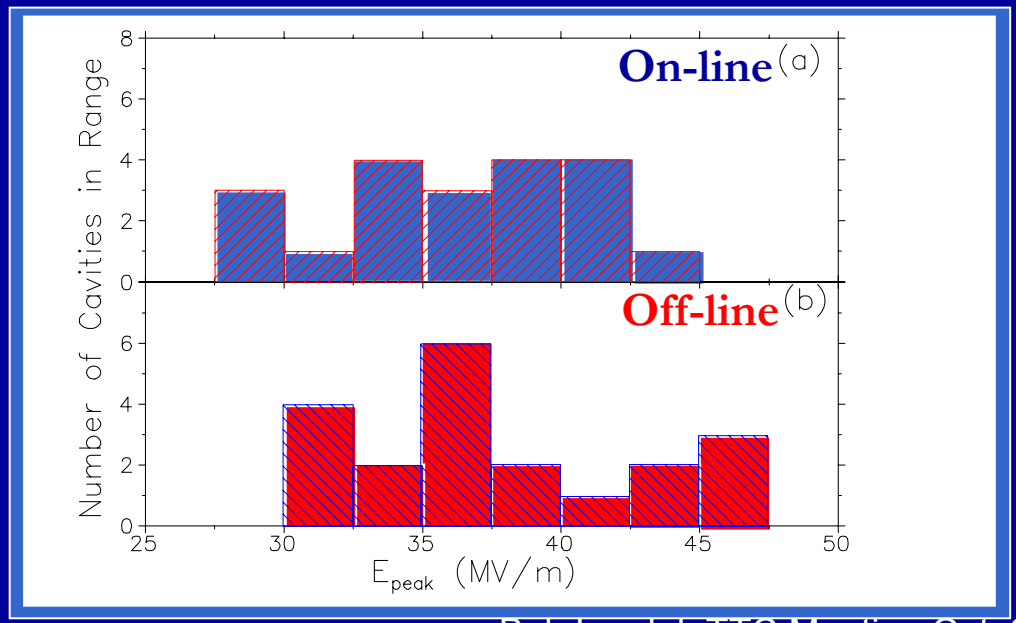
Coupling Loop



Mechanical Tuner

Cavities: On-line vs. Off-line Performance

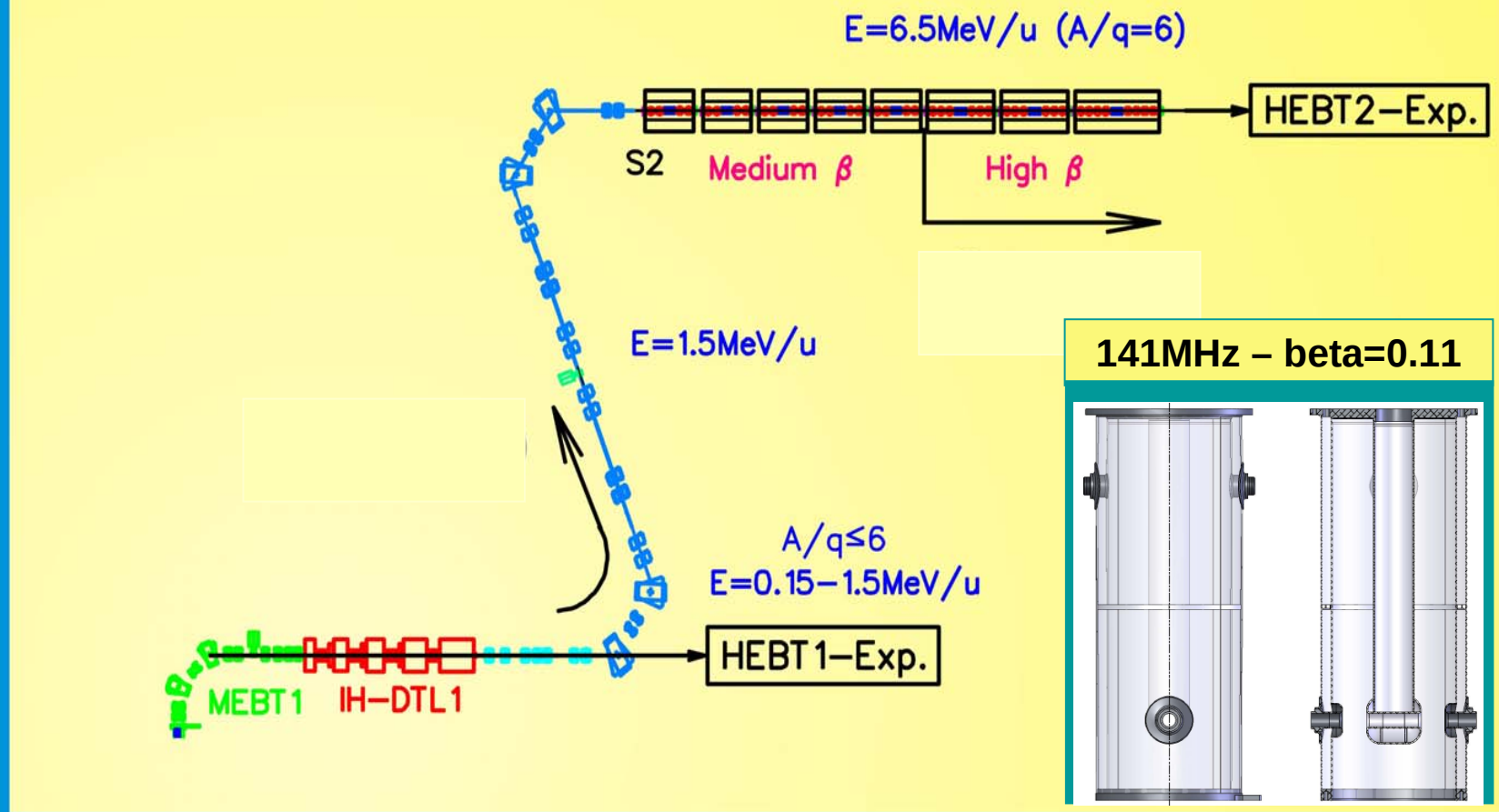




- On-line gradients calculated from beam acceleration at 7W/cavity averaged over three different ions. The average gradient for the on-line cavities is 7.25MV/m corresponding to a peak surface field of 36MV/m
- Off-line results give an average gradient at 7W/cavity of 7.6MV/m corresponding to Ep=38MV/m
- Some contamination evident in a few cavities but on-line performance down by only 5% from off-line tests

ISAC-II Phase II

ISAC-II (Phase II - High Velocity Section - 2009)



141MHz – beta=0.11

- The Phase-II Extension of ISAC-II calls for the addition of 20 higher velocity (β=0.11) quarter wave cavities by the end of 2009
- The twenty cavities will be housed in three cryomodules and add an additional 20MV to the ISAC-II ions

PAVAC

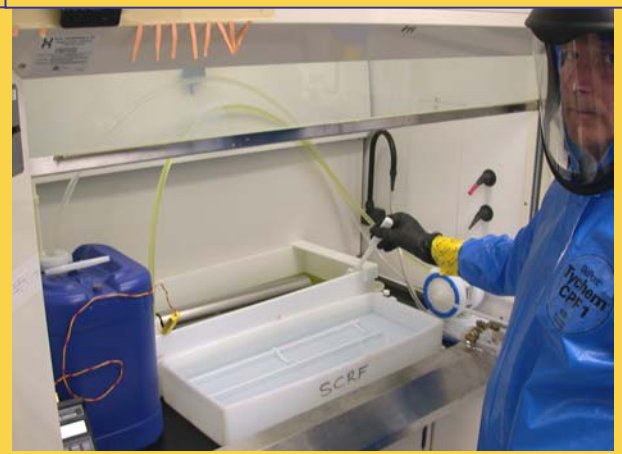
- Who is PAVAC?
  - A Canadian Company located in Richmond B.C.
- Specializing in
  - Electron Beam Welding
  - Precision machining
  - Pulsed Electron Beam Coating

First Frequency Tuning

Forming and Machining

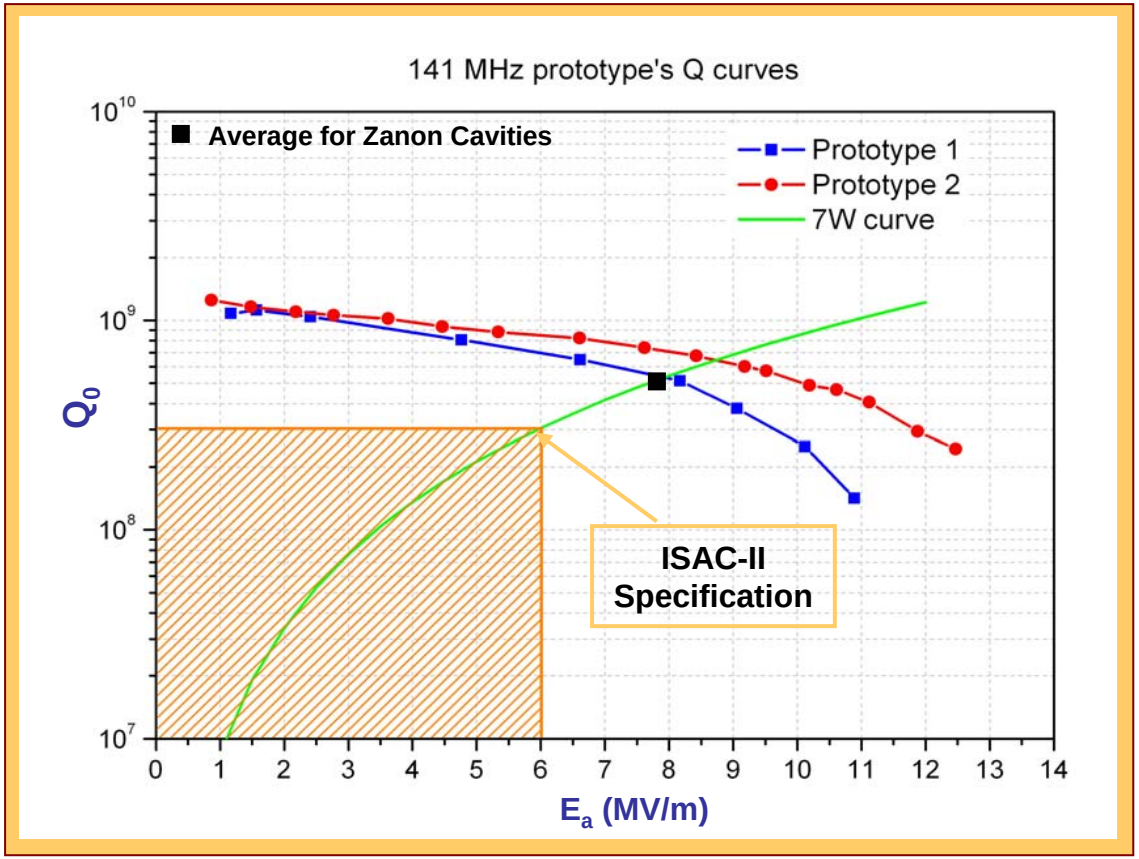
Electron Beam Welding

Pre-weld Etching - TRIUMF



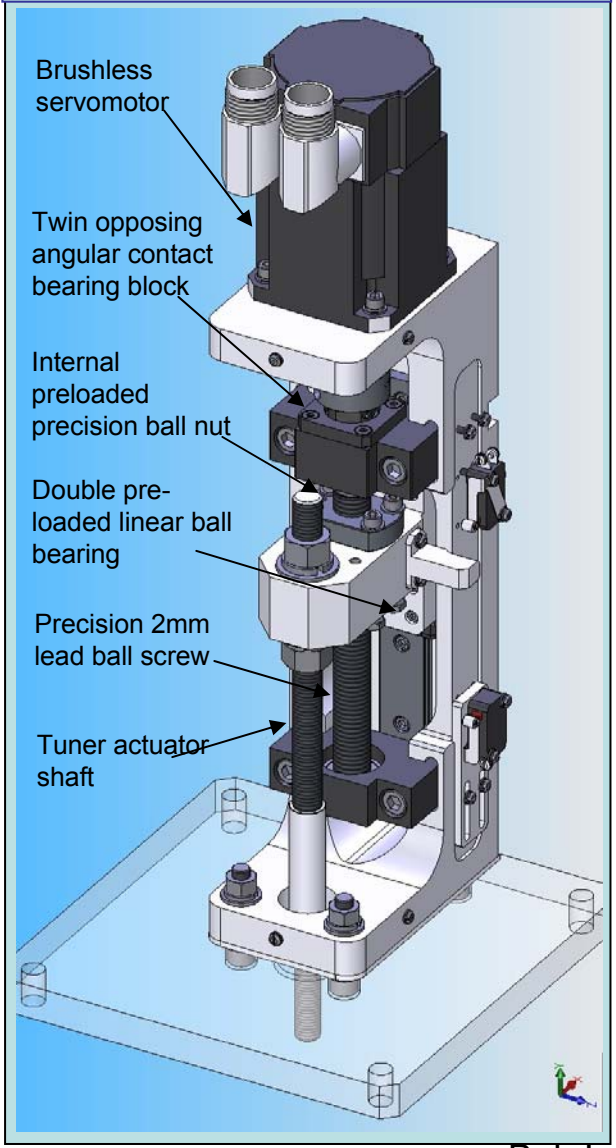
Two Prototypes Tested

- Two prototypes fabricated in copper and two in bulk niobium
- Both niobium prototypes perform significantly above ISAC-II specifications; average values of E_a=8.4MV/m (Ep=41MV/m) - specification 6MV/m
- Average voltage gain Va=1.5MV @ 7W



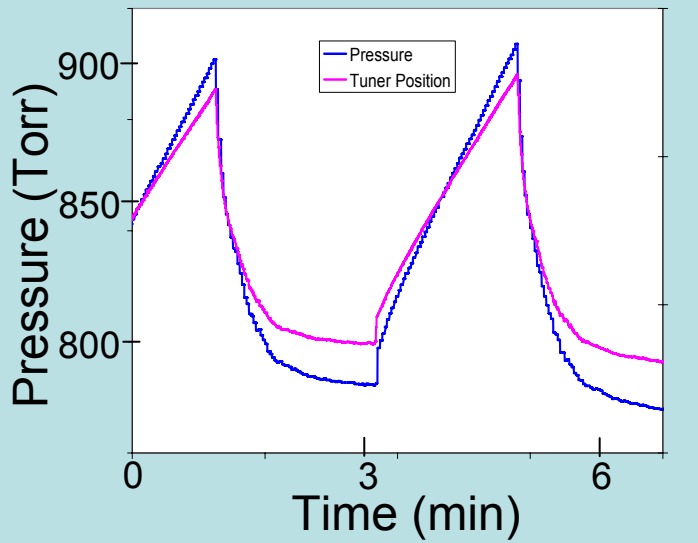
Phase II Linac: RF Tuner

New Tuner Motor Developed



- precision brushless servo-motor and ball screw on top of cryomodule
- Actuator extends (through bellows) to a lever mechanism to the tuning plate
- Tuner Position resolution 0.04 Hz/step; corresponds to 5nm/step

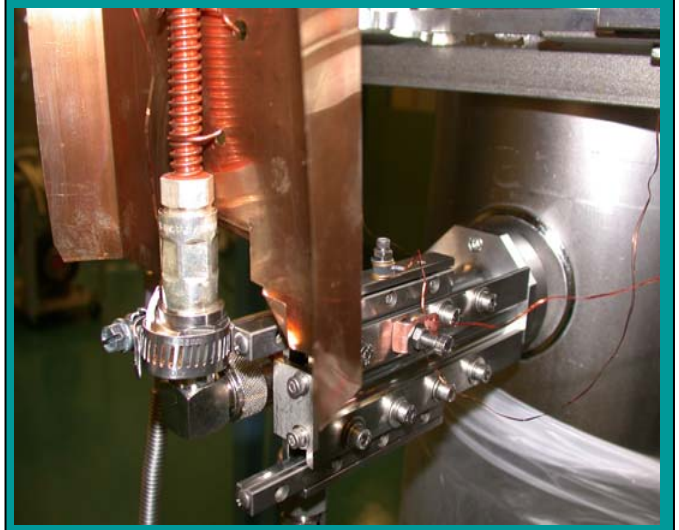
- Tuner operation in locked phase loop @ 6.4MV/m, Pf=166W, Pc=3.3W, Qo=7.13e8 coupling beta~200, bandwidth ~±20
- Force helium pressure fluctuations to test tuner
- ΔP=137 T, Δf=330Hz;
- compensation is $\Delta f/\Delta t$ =13Hz/sec.
- No increase in phase noise during test.

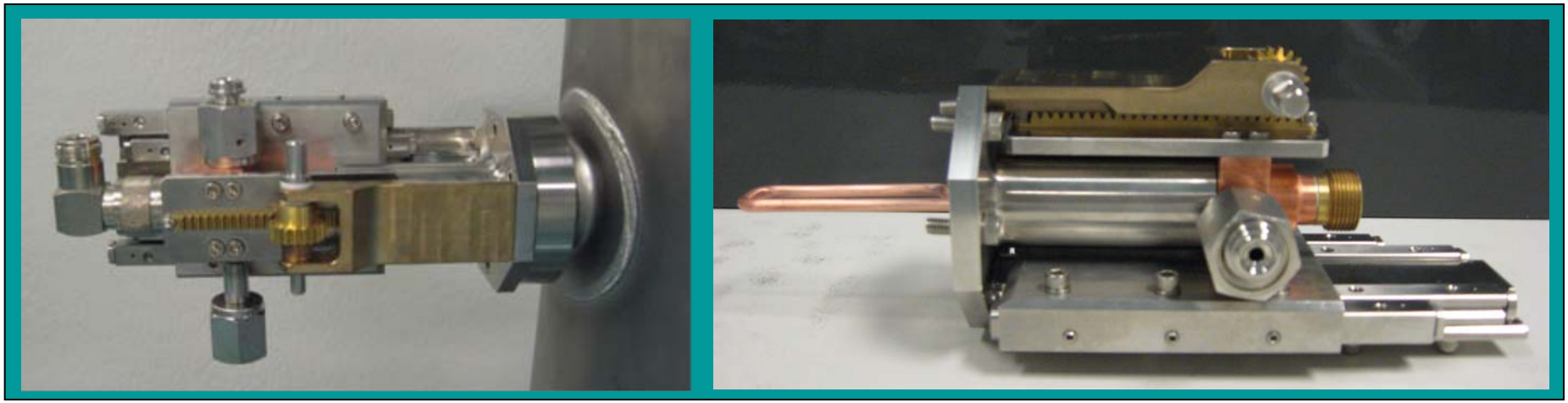


Coupling loop

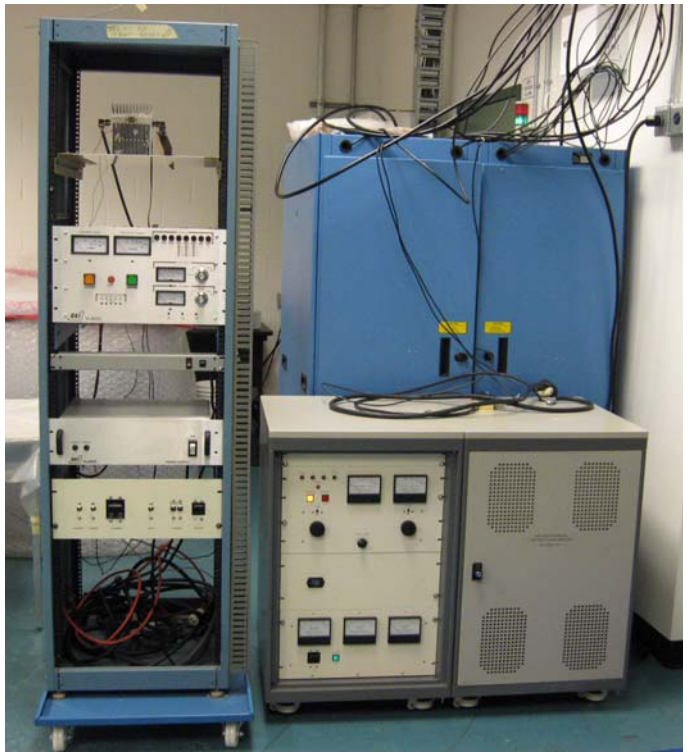
- developed new coupling loop with improved mechanical drive
  - Uses non-magnetic cross roller bearings
  - Reduce side loads by making the LN2 feed more symmetric
  - Performance tests show at Pf=200W the heat load to the helium is <0.5W

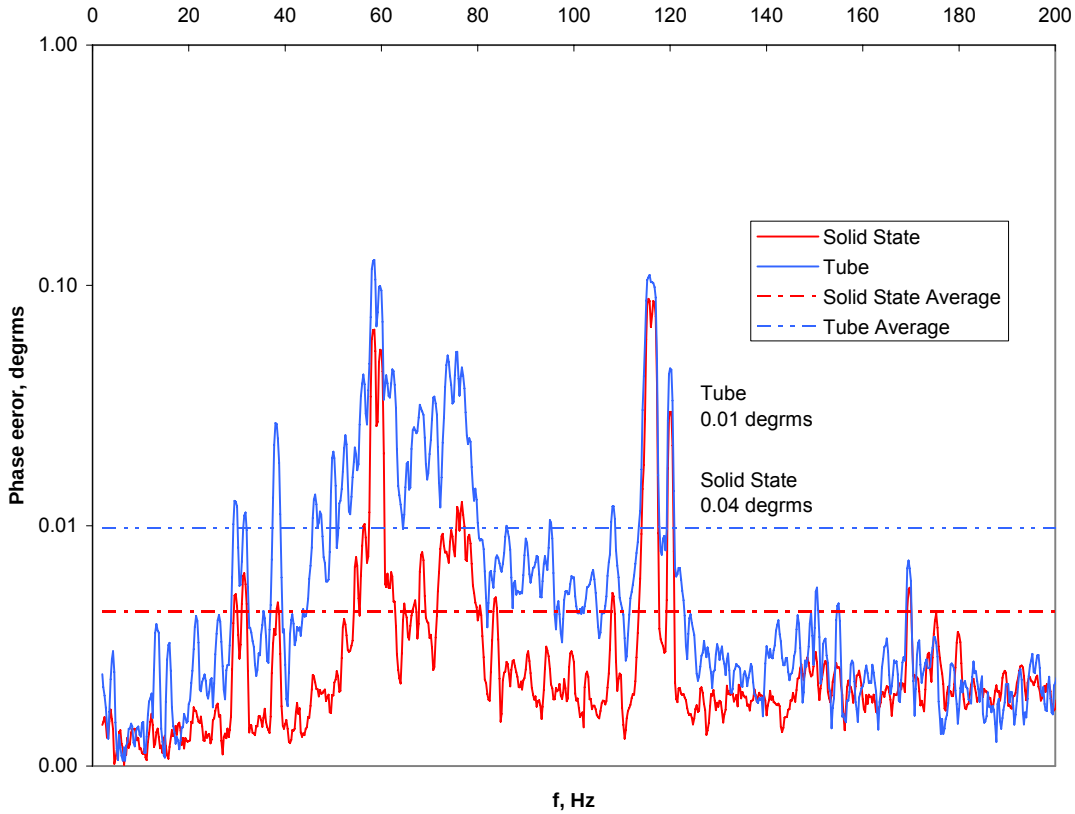
SCC coupling loop





RF Amplifiers – Moving to Solid State

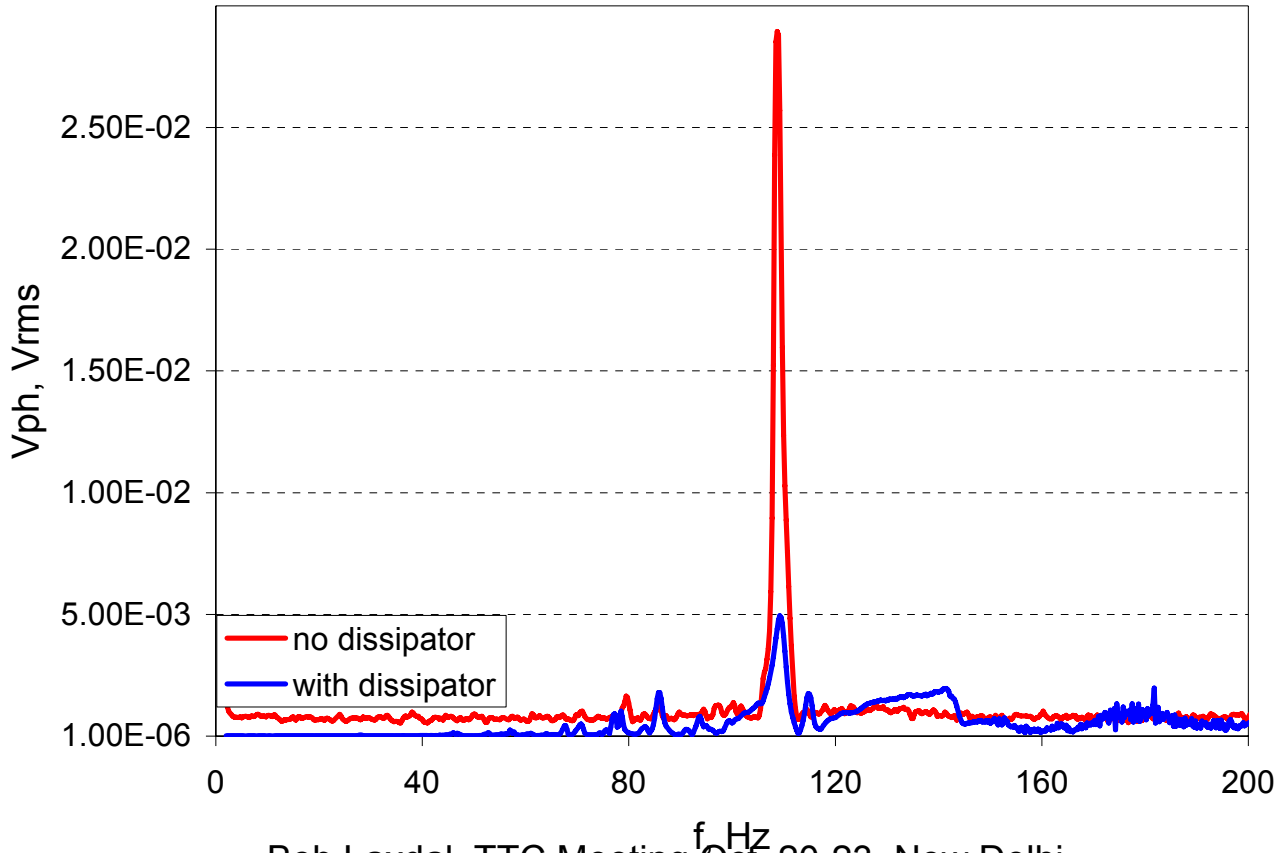




Solid State Amplifier from QEI designed for ISAC-II Phase II Cavities showed very good performance and twice less noise level in RF System of the cavity in comparison with tube amplifier

Mechanical Dissipator Performance

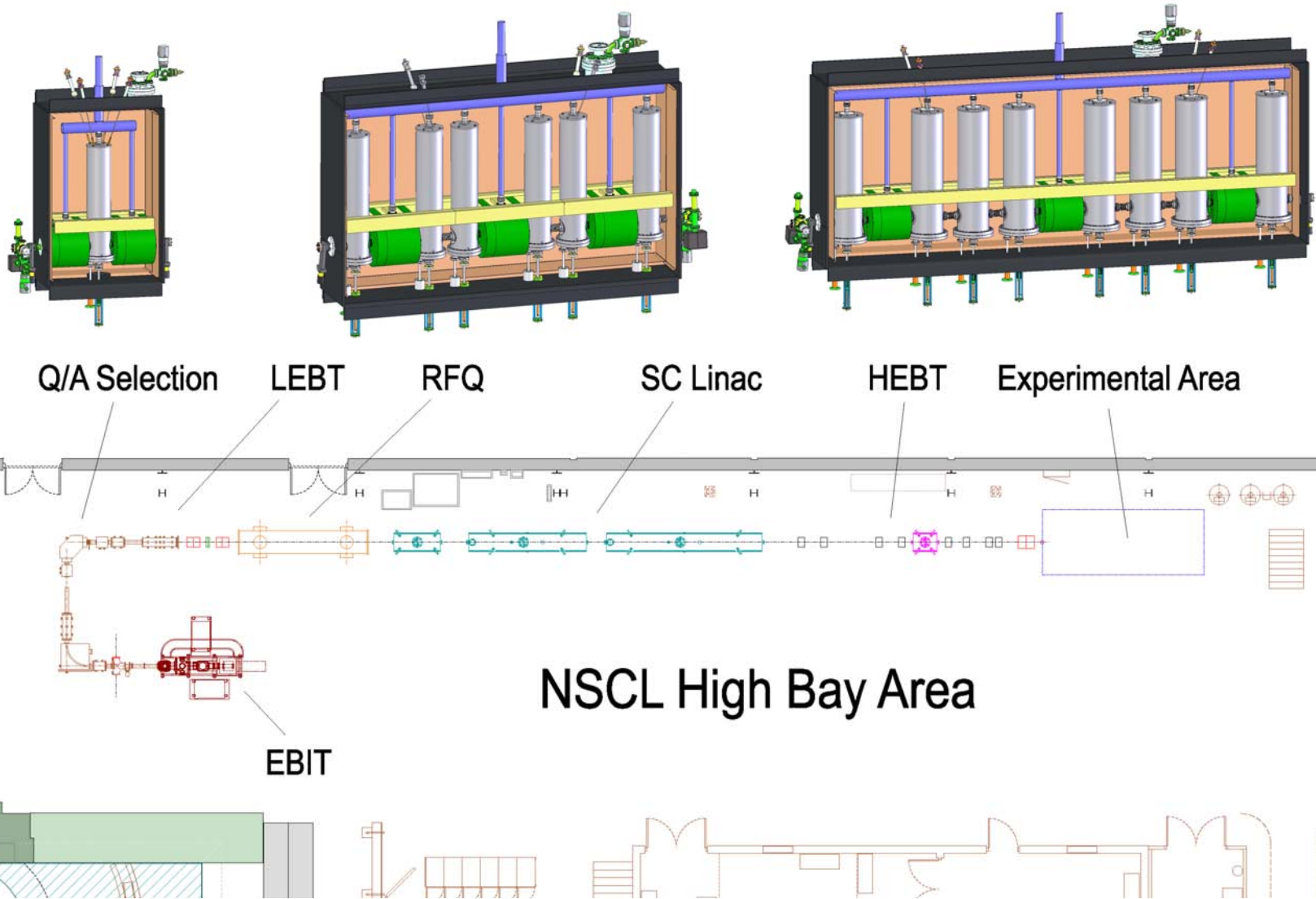
•Tuner motor used to drive mechanical noise on the top of the cryostat
•Cavity lowest mechanical resonance ~110 Hz which is from inner conductor
•110 Hz frequency deviation without and 19 Hz with dissipator at the same excitation amplitude



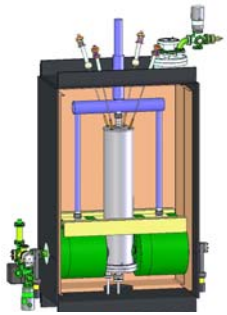
MSU

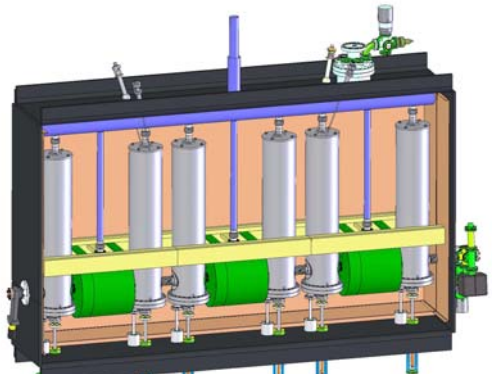
MSU Reaccelerator Project

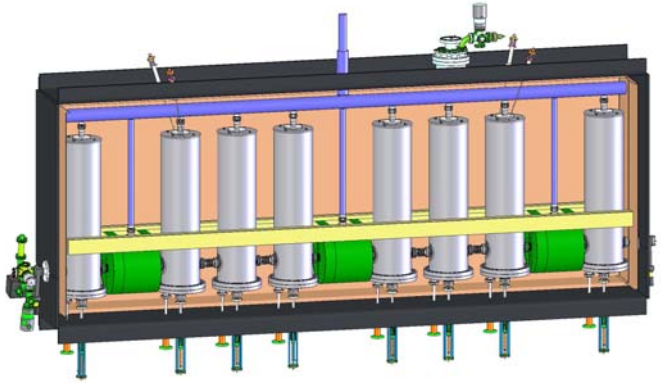
In house construction of three cryomodules, including fabrication and processing of 20 quarter-wave cavities



Superconducting Linac Cryomodules



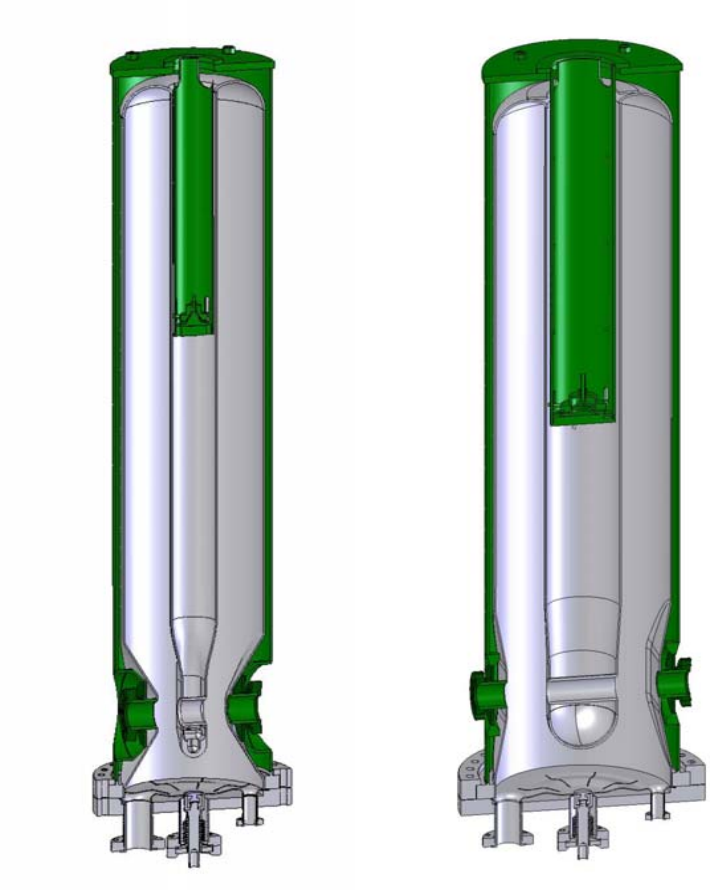




- 1st Cryomodule
  - 2 Superconducting solenoids
  - 1 $\lambda/4$ SC cavity, $\beta_{opt}=0.041$
  - Transverse and longitudinal matching
- 2nd Cryomodule
  - 3 Superconducting solenoids
  - 6 $\lambda/4$ SC cavities, $\beta_{opt}=0.041$
  - Acceleration/deceleration: 1.2/0.3 MeV/u
- 3rd Cryomodule
  - 3 Superconducting solenoids
  - 8 $\lambda/4$ SC cavities, $\beta_{opt}=0.085$
  - Acceleration/rebunching

Two SRF Cavity Types Used

$\beta_{opt}=0.041$ $\beta_{opt}=0.085$

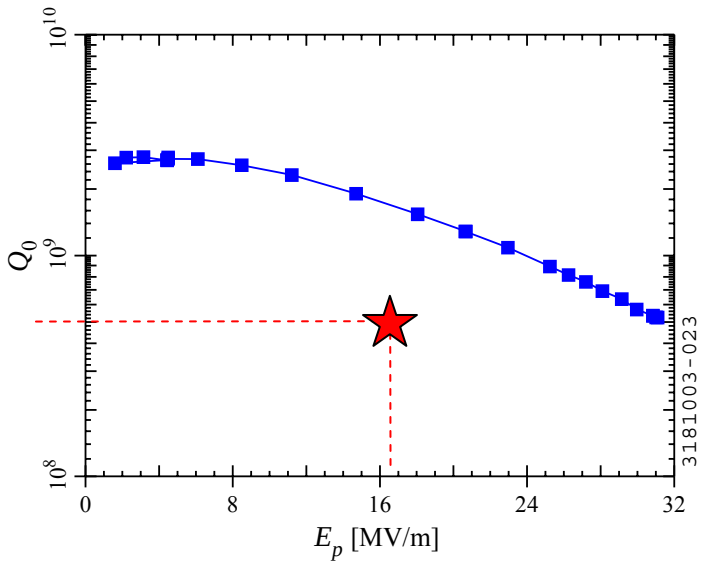


Type	λ/4	λ/4
Optimum β	0.041	0.085
Frequency	80.5 MHz	80.5 MHz
Epeak	16.5 MV/m	20.0 MV/m
Vacc	0.46 MV	1.18 MV
Eacc	4.84 MV/m	5.62 MV/m
Bpeak	28.2 mT	46.5 mT
Temperature	4.5 K	4.5 K
Length	0.095 m	0.21 m
Aperture	30 mm	30 mm

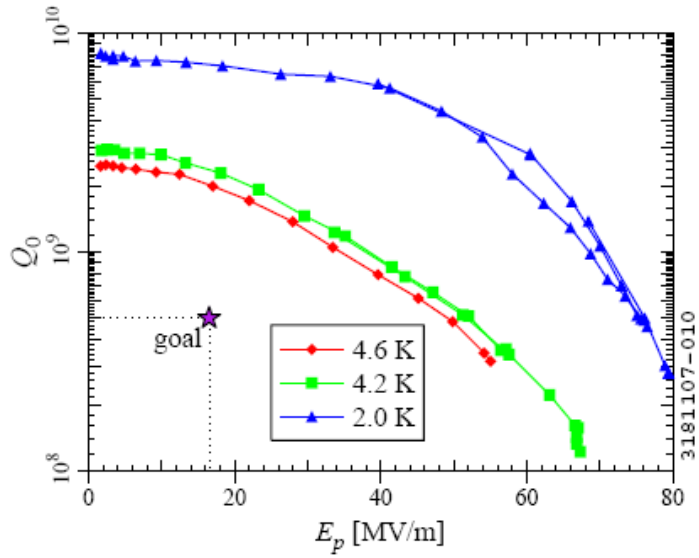
MSU Reaccelerator

SRF Cavity Prototype R&D

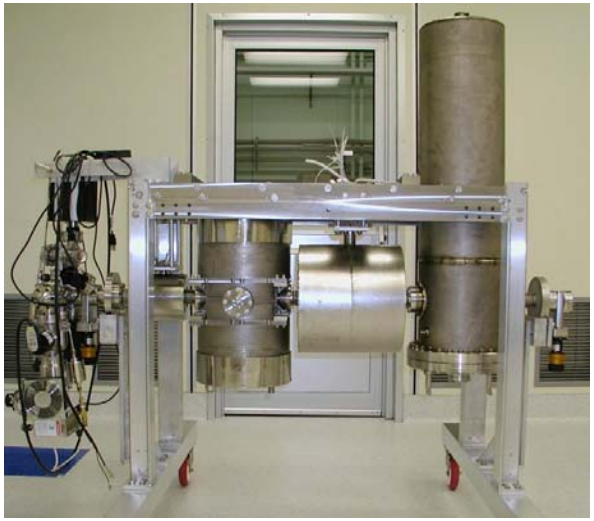
- QWR b_{opt}=0.085 prototyped and tested in 2003
  - Q_0: 5×10^8
  - E_p: 20 MV/m



- QWR b_{opt}=0.041 prototyped and tested in 2007
  - Rs=2nΩ
  - Toroidal shorting plate a la Spiral and ANL
  - TRIUMF slotted tuning plate



SC Linac Prototype Cryomodules



(a) cold mass

(c) inner MLI

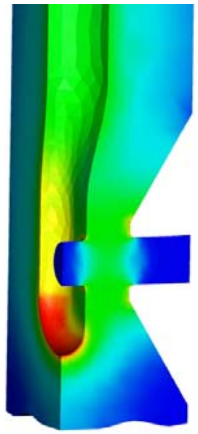
(e) outer MLI

(b) top plate

(d) 77 K shield

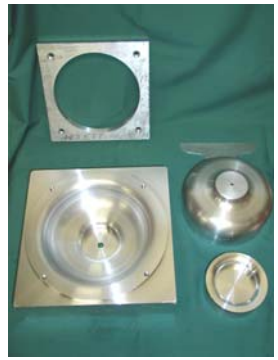
(f) vacuum vessel

SRF Cavity Design, Fabrication, and Testing



E & M Modeling and Cavity Design

Cavity Machining



Cavity Forming

Cavity Etching

Cavity Cleaning

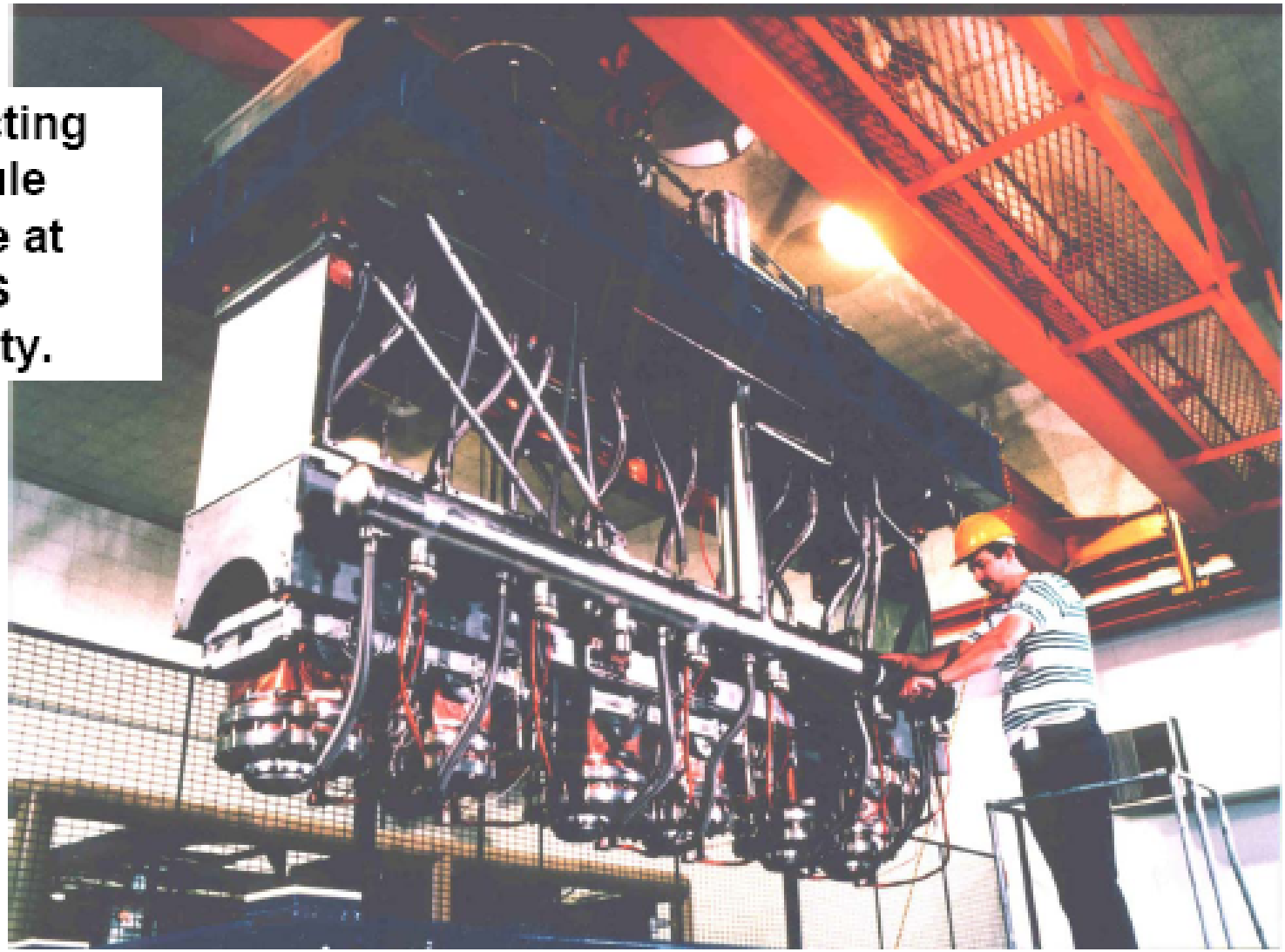
Cavity Insert Assembly

Cavity Testing

Argonne

Argonne-ATLAS

A superconducting linac cryomodule currently in use at the ANL/ATLAS heavy-ion facility.



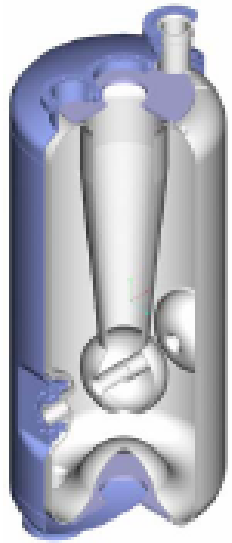
ANL Energy Upgrade

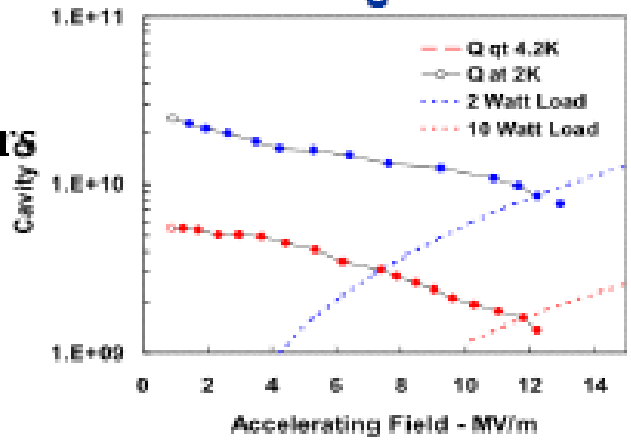
ATLAS Energy Upgrade and Refrigerator Improvements

ATLAS Energy Upgrade will replace the last ATLAS cryostat with:

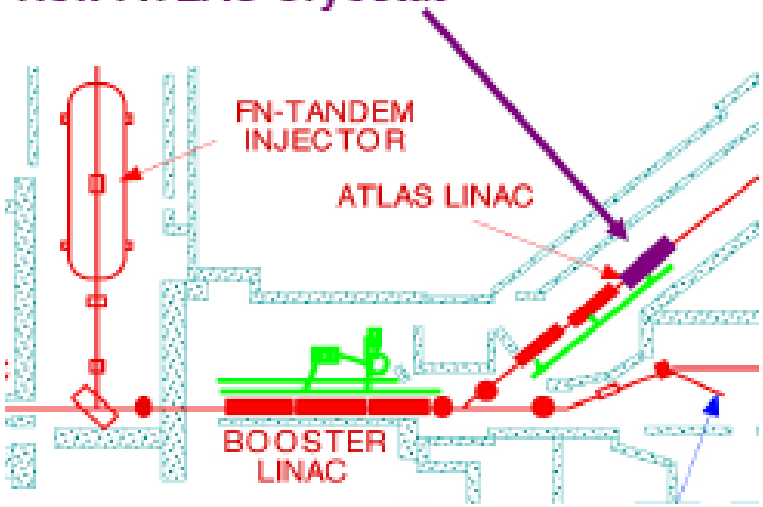
New cryostat containing
New class of resonators:
- 7 ß=0.14 quarter-wave resonators
- ß=0.26 half-wave resonator

109 MHz
QWR Cavity
$ß_s$ = 0.144
Length = 25cm





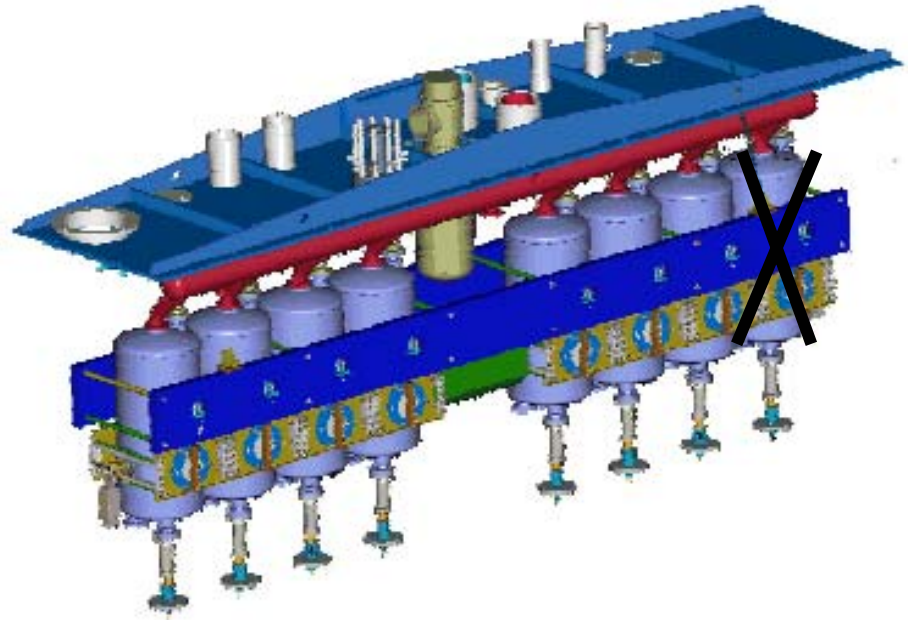
New ATLAS Cryostat



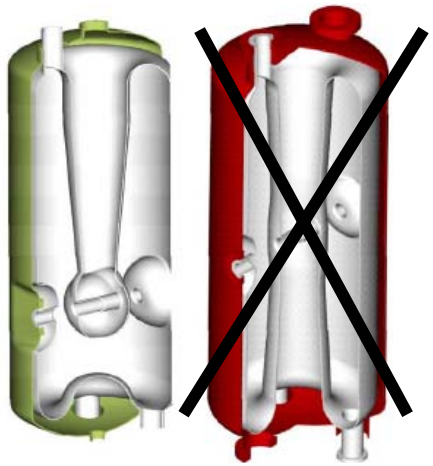
	Current ATLAS		ATLAS Upgrade	
A	No Strip	Strip	No Strip	Strip
16	13.0	15.7	18.5	21.5
40	12.4	13.4	17.5	19.9
58	9.9	11.8	13.5	17.9
78	9.5	11.2	12.8	16.7
132	8.0	9.3	10.4	13.4
197	6.6	7.9	8.4	10.9
238	6.4	7.4	7.9	10.0

Atlas Energy Upgrade Cryomodule

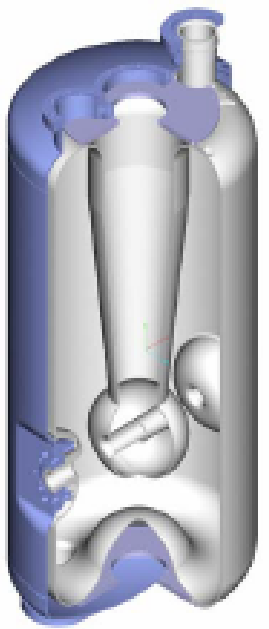
Cryomodule nearing completion
- Cavities
  - 7 QWR's (115MHz, beta=0.15)
- Energy booster downstream of ATLAS with expected increase in Atlas final energy >30%
- Separated vacuum system



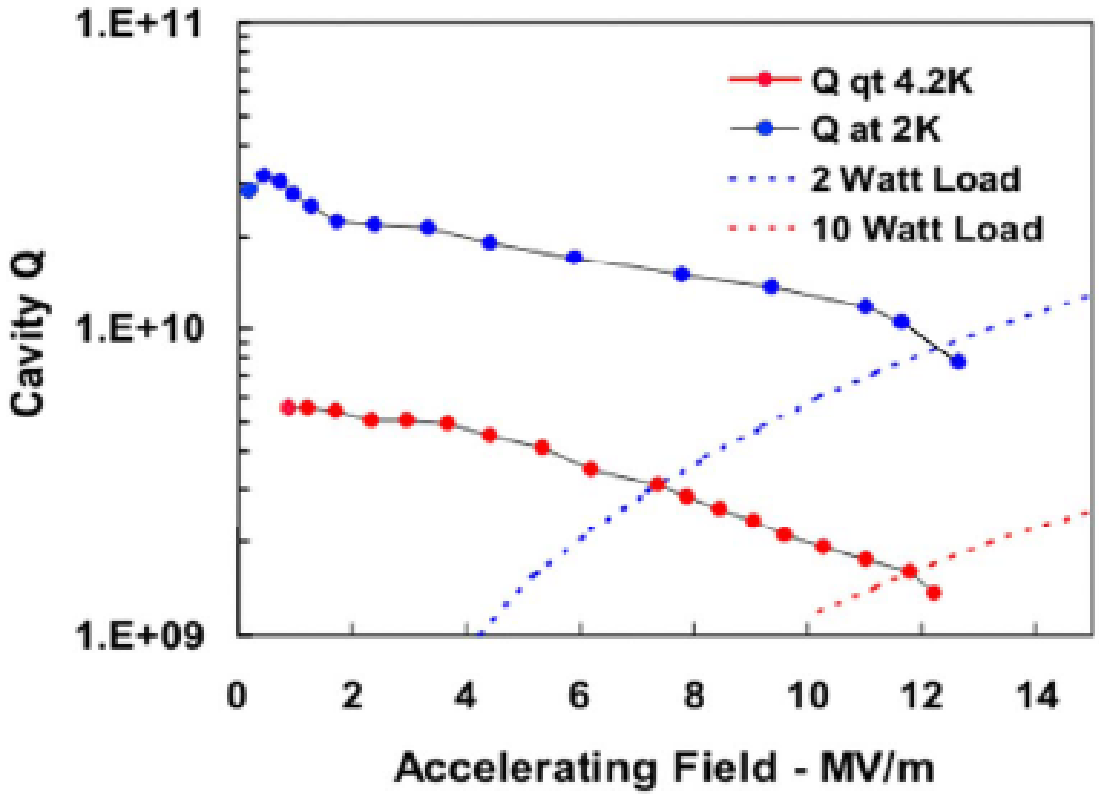
type	*QWR*	*HW*
f	115 MHz	172.5 MHz
Bgeom	0.15	0.26
Length	25 cm	30 cm
QRs	42	58
at an accelerating field of 1 MV/m		
Epeak	3.2 MV/m	2.9 MV/m
Bpeak	57 G	78 G
rf energy	170 mJ	345 mJ



Upgrade quarter wave

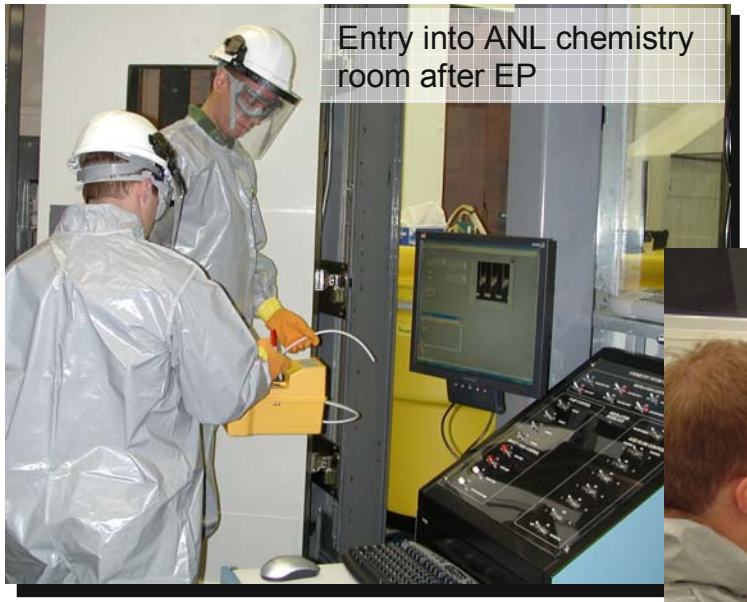


QWR 109 Parameters		
Frequency	109.125	MHz
Geometric Beta	0.144	v/c
Active Length	25	cm
QRs	40	ohm
Epeak/Eacc	3.2	
Bpeak@ 1 MV/m	58.3	Gauss
RF Energy/Eacc^2	0.1662	Joule



EP at Argonne

Commissioning the SCSPF: Electropolishing

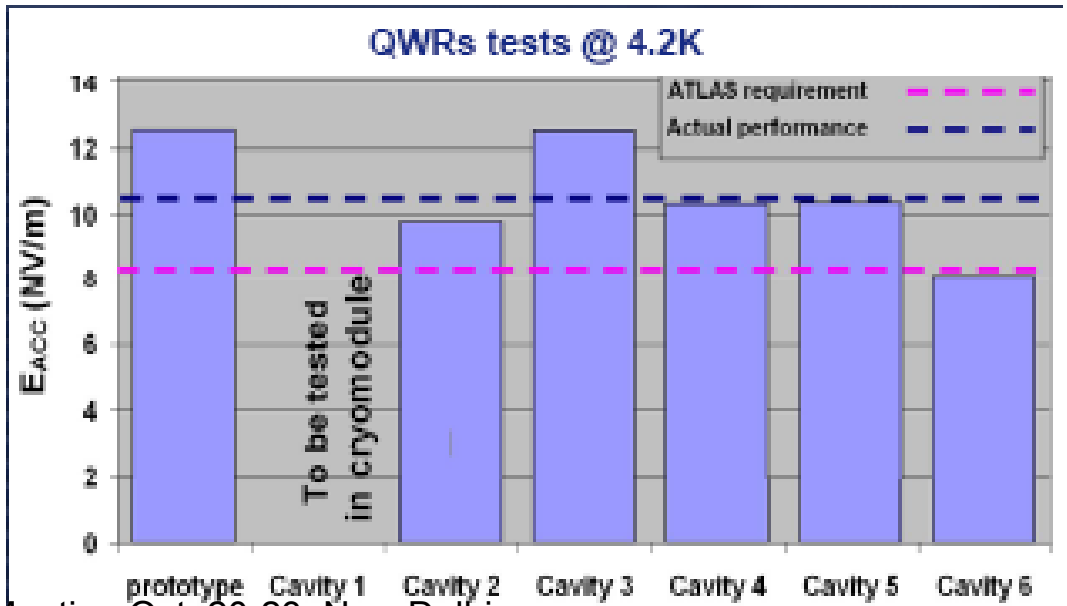


Entry into ANL chemistry room after EP

Last of 6 QWR for ATLAS Upgrade, May 07

Upgrade Cryomodule

- Separate vacuum system
- Average performance of Ep=33MV/m at 4.2K



FRIB (RIA Lite)

- Site evaluations are on-going this month
- Both MSU and Argonne have prototypes in hand to move forward if funded

115 MHz, β =.15

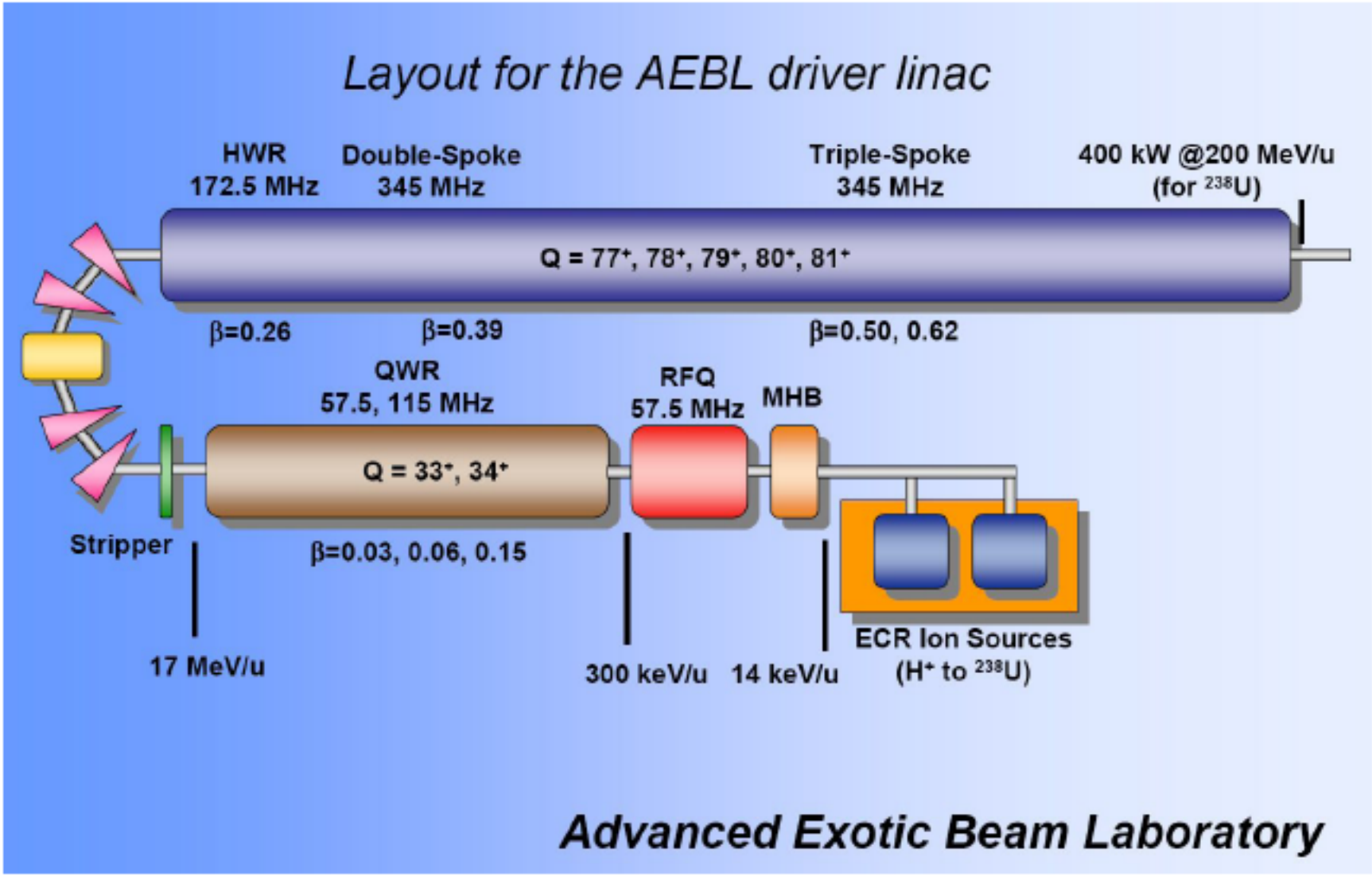
172.5 MHz, β =.25

345 MHz, β =.4

All 3 prototypes have been completed and significantly exceeded baseline specifications for the RIA driver

AEBL Driver – FRIB Proposal

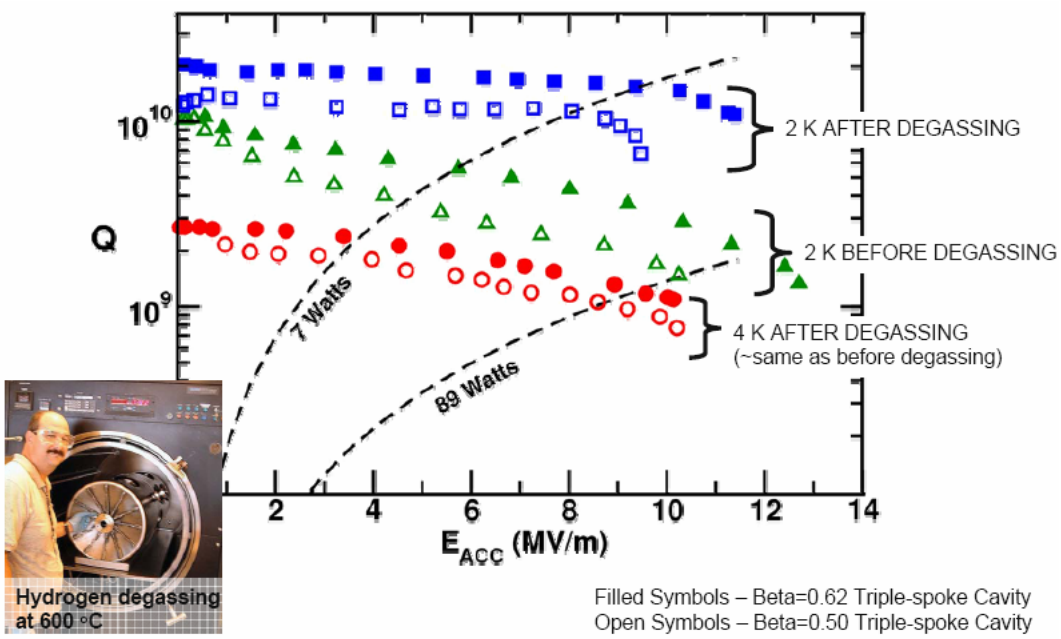
II. Applications: Spoke –cavity based AEBL

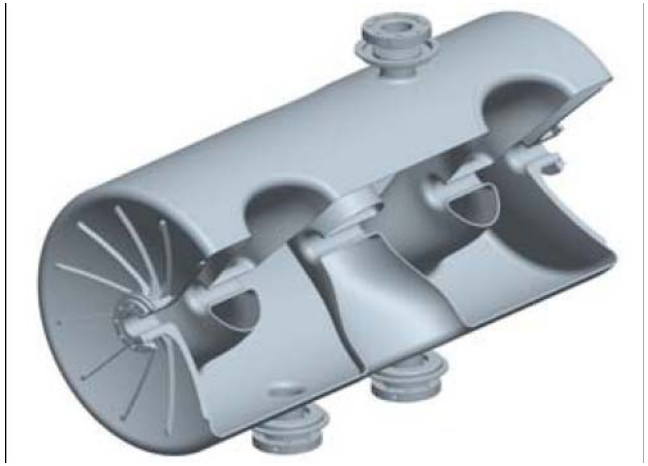


Reference [9]

ANL – Argonne USA

- 345MHz Triple spoke cavity developed over last several years for beta=0.5 and 0.62
- Now proposed for Project X to replace elliptical cavities in mid beta range
- Q-slope apparent at 4K virtually disappears at 2K after hydrogen degassing
  - Enhancement in Q at high field is more than just reduction of Rbcs

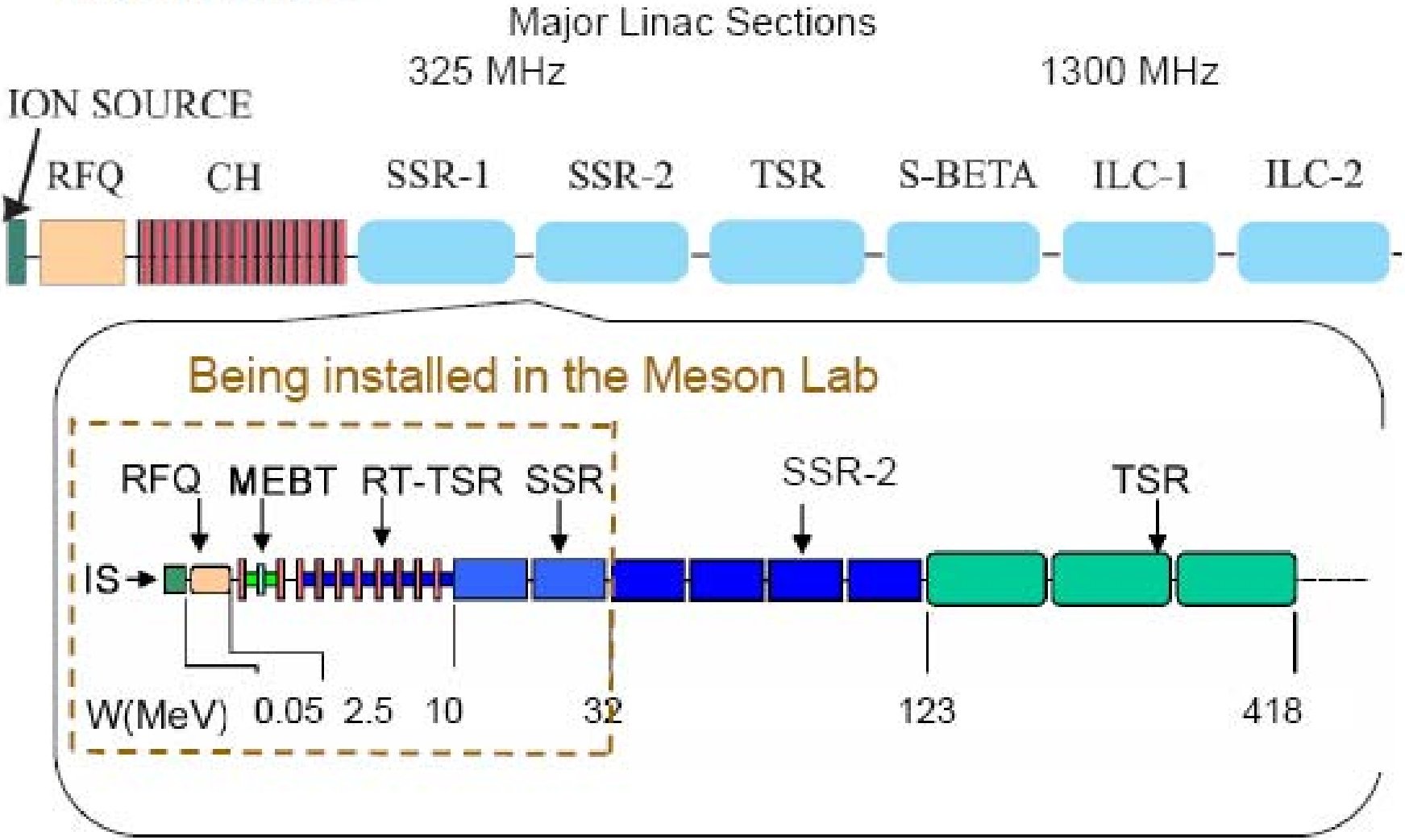




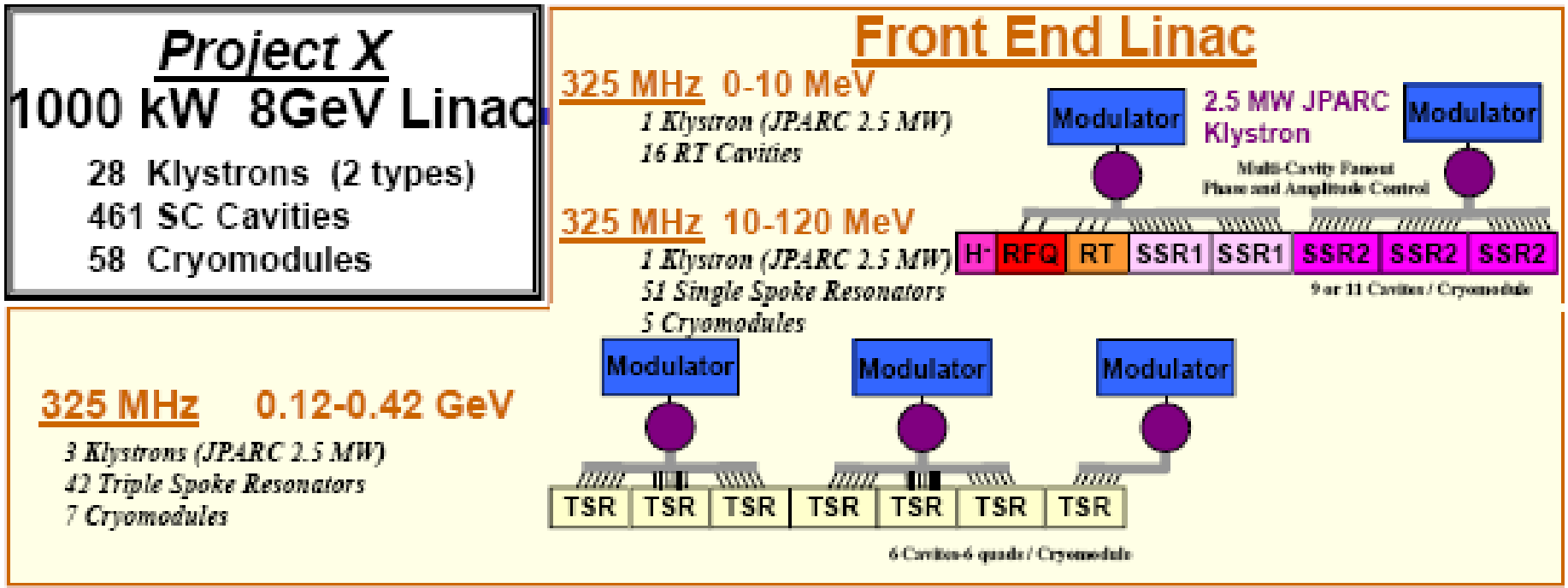
FNAL

Project X

Linac Structure



Project-X RF



•Cold section starts at 10MeV with 51 single spoke resonators to 120MeV followed by 42 triple spoke resonators to 420MeV

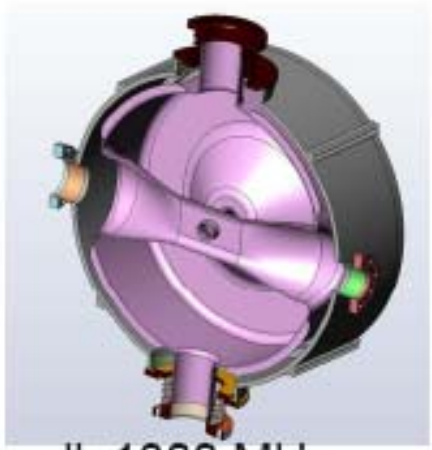
Project X

Accelerating cavities (not to scale)

NC spoke

SC single spoke

Triple-spoke cavitiy

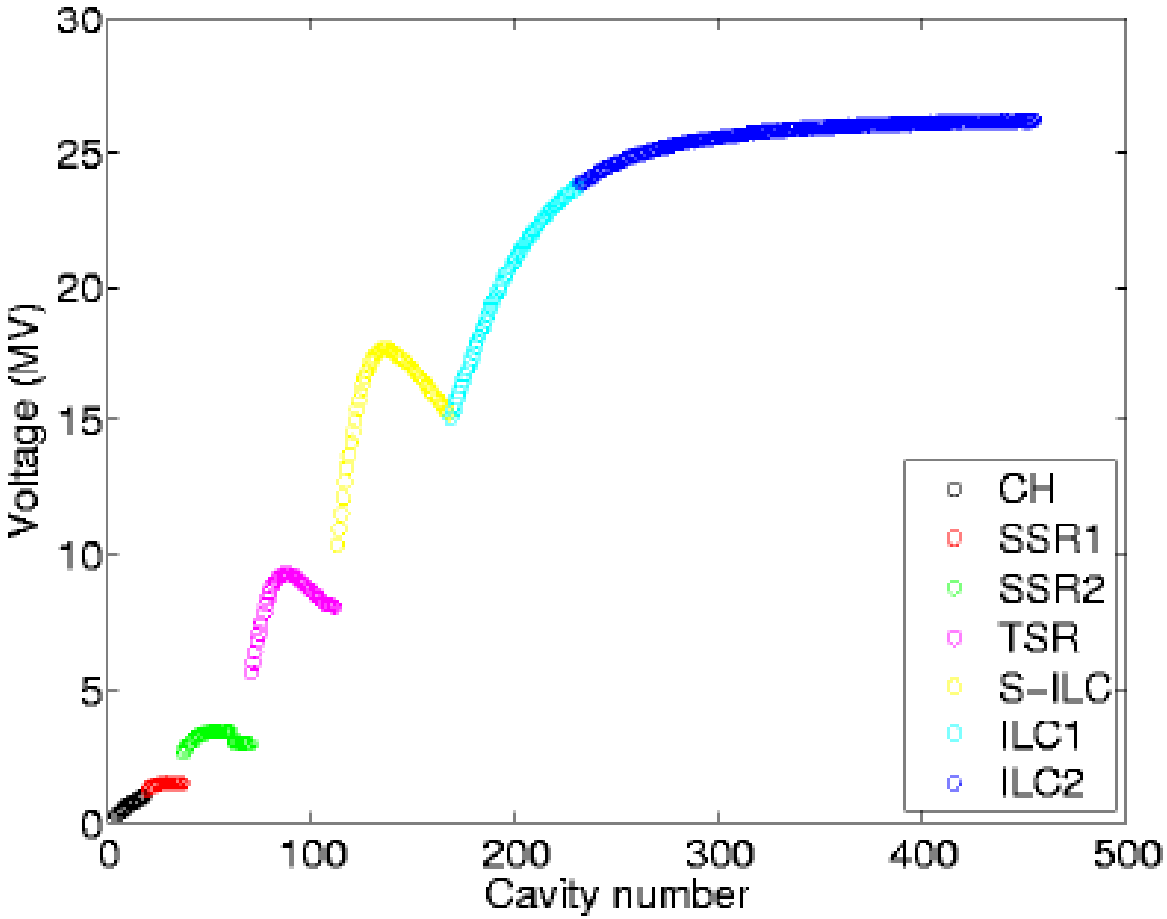


β_G=0.81, 7-cell, 1300 MHz

ILC, 9-cell

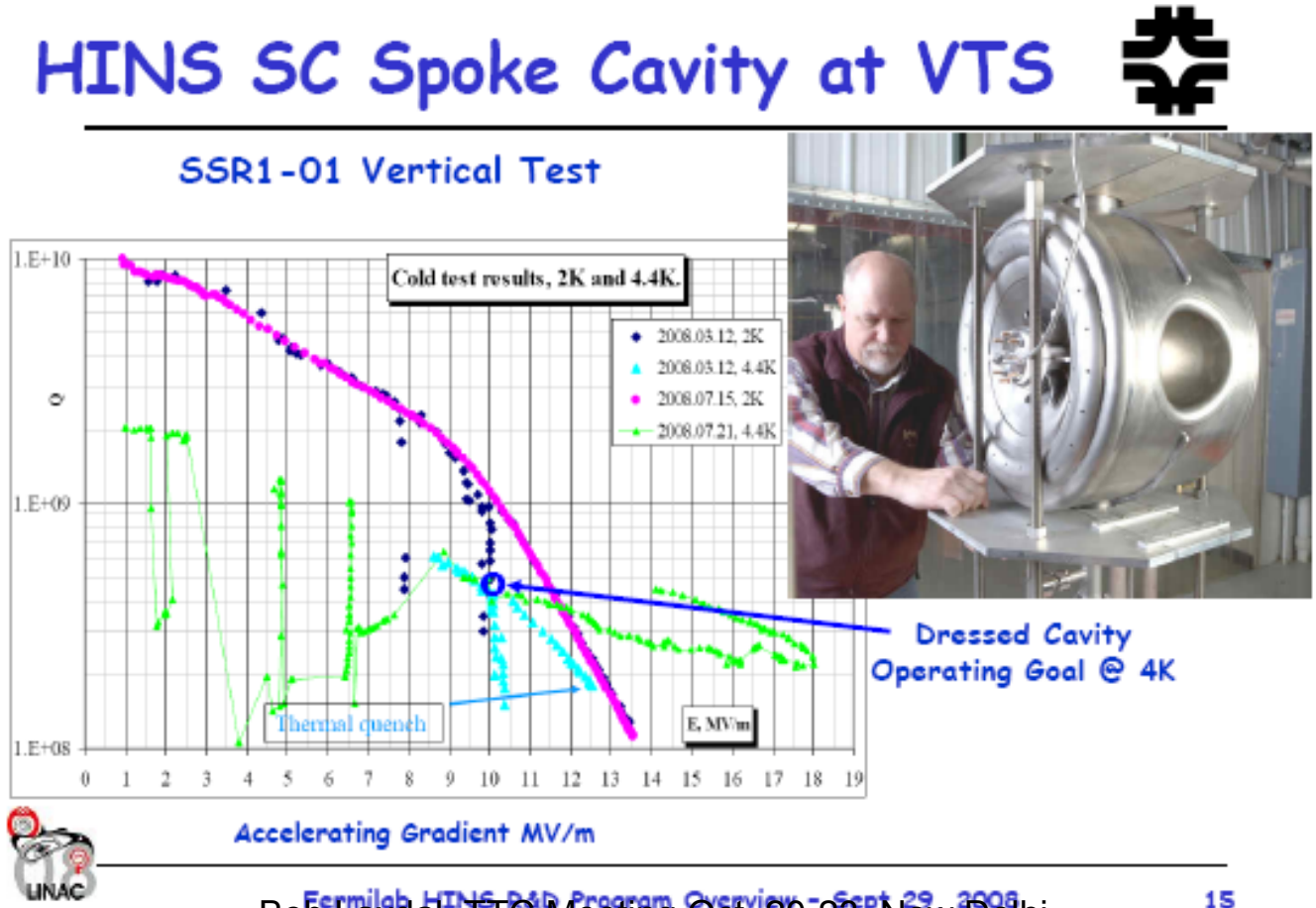
Project X

Voltage gain per cavity



HINS Project

- What is HINS?
  - A 60MeV test linac to demonstrate beam dynamics and rf feed capabilities of the Project X front end design



Conclusion

- On-going projects in North America of ISAC-II Phase II, MSU reaccelerator and Argonne energy upgrade keep interest strong in Low beta community
- Community very interested in new developments concerning HINS/Project X to prove the capability of spoke resonators at mid energy regime
- Waiting for positive response to FRIB funding